Before the
FEDERAL COMMUNICATIONS COMMISSION
Washington, D.C. 20554

In the Matter of	)	
	)	
Creation of a Low Power Radio Service	)	MM Docket No. 99-25
	)	
	)	RM-9208
	)	RM-9242
	)	
	)	

Comments of the National Association of Broadcasters

VOLUME TWO OF THREE

Technical Studies and Reports

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Volume Two

SUMMARY OF VOLUME TWO

Volume Two of NAB's Comments in MM Docket 99-25 contain the technical studies, reports and analyses prepared in response to the Commission's LPFM proposal. These documents are attached as Exhibit A, Exhibit B and Exhibit C.

Exhibit A is the Moffet, Larson & Johnson ("MLJ") Engineering Report, "Standard of Service for FM Receiver Tests." This report developed the audio standard of service that was used in NAB's receiver testing. MLJ concluded that the most comprehensive and generally acceptable standards were contained in International Telecommunications Union-Radiocommunication (ITU-R) Recommendation 641.

Exhibit B contains the Carl T. Jones report, "FM Receiver Interference Test Results Report." This report outlines the test methodology, test system parameters, test procedure and results of the receiver testing. The report also contains a description of each of the radios tested and a graphical representation of the results.

Exhibit C is the MLJ report, "Selection of Receivers for FM Receiver Testing and Analysis of Test Results." In this report, MLJ analyzes the receivers that were tested and reviews the results of the testing. MLJ concludes that the receivers tested are representative of receivers used by the public at this time, and that the interference ratios measured in NAB's receiver study show that receivers have generally not improved in their ability to reject adjacent channel interference since the 1940s. Consequently, if the Commission were to allow LPFM stations to operate within a station's service contour, they would cause much more interference than predicted.

EXHIBIT A:

Standard of Service for FM Receiver Tests

MLJ *MOFFET, LARSON & JOHNSON, INC.*
CONSULTING TELECOMMUNICATIONS ENGINEERS

ENGINEERING REPORT

1110 N. Glebe Road, Suite 900 **Arlington, VA 22201**

Standard Of Service For FM Receiver Tests In Support Of The Comments Of The National Association Of Broadcasters MM Docket No. 99-25

July 21, 1999

MLJ *MOFFET, LARSON & JOHNSON, INC.*
CONSULTING TELECOMMUNICATIONS ENGINEERS

ENGINEERING REPORT

1110 N. Glebe Road, Suite 900 **Arlington, VA 22201**

National Association of Broadcasters
Washington, DC

Standard of Service for FM Receiver Tests
In Support Of The Comments Of
The National Association of Broadcasters
MM Docket No. 99-25

Introduction

MLJ, Inc. has been retained by the National Association of Broadcasters (NAB) to conduct engineering studies in support of the NAB comments in MM Docket No. 99-25. In this proceeding the FCC proposes to create a low power FM broadcasting service (LPFM). The purpose of this study is to develop an audio standard of service, that is an audio signal-to-noise ratio (S/N) and desired signal levels, to be used in the measurement program sponsored by NAB to determine the interference susceptibility of contemporary FM broadcast receivers.

The FCC has no standards for this purpose, therefore a search of the technical literature was conducted to locate appropriate standards and studies. This report also relates available standards to the present Commission standards for FM coverage and interference. The most comprehensive and generally acceptable standards relating to FM service and interference are contained in recommendations of the International Telecommunications Union-Radiocommunication (ITU-R). FM receiver interference susceptibility measurements are based on procedures presented in ITU-R (formerly CCIR) Recommendation 641.[1] Section 6 of Recommendation 641 specifies an audio S/N of 50 dB assuming that receivers can produce a S/N of 56 dB without interference. The ITU standard of 50 dB is compared to ratios used in the development of the FCC standards and the measured ratios in the receiver noise limited case.

Present FCC Standards

The present FCC allocation standards are based upon predicted desired coverage and interfering field strength contours. In the band reserved for non-commercial educational (NC/E) use, the location of the contours is calculated and the contours are not allowed to overlap. In the commercial band, distance separations are used which are the sum of the distances to the protected coverage and interfering contours based upon maximum facilities stations. Co-channel, first, second and third adjacent channel interference cases are considered in the FCC rules. The following tables show the values of the protected contours, and the desired to undesired (D/U) interference ratios for non-commercial allocations and the ratios that are used to derive the distance separations for commercial FM allocations:

FM Class	Protected Contour (dBu)
Commercial B	54
Commercial B1	57
All Others	60

[1] Recommendation 641 "Determination of Radio-Frequency Protection Ratios For Frequency-Modulated Sound Broadcasting", 1986, ITU, Geneva, Switzerland.

Interference Case	Desired to Undesired Interference Ratio (D/U) (dB)
Co-Channel	20
First Adjacent	6
Second Adjacent NC/E	-20
Second Adjacent Commercial	-40
Third Adjacent	-40

The Commission's standards also protect reception of signals from IF interference. Conventional FM receivers convert all channels from their radio frequency (RF) to an intermediate frequency (IF) of 10.7 MHz for further amplification. Stations separated in frequency by 10.6 or 10.8 MHz can produce a "beat" signal which falls in the IF passband and can potentially interfere with the reception of the weakest of the IF separated pair. In addition, two IF separated stations can interfere with the reception of FM stations on any channel when the signal is weak. In this case, interference occurs when the signals of both IF spaced stations are strong. The FCC standards for IF interference are distance separations that are based upon non-overlapping field strength contours of 36 mV/m (approximately 91 dBu).

Conversion of Field Strength to Received Power

Assuming a half wave dipole receiving antenna, received power, P_r, in dBm is calculated from field strength, F, in dBu and frequency, f, in MHz from the expression:

$$P_r = F - 20 \operatorname{Log} f - 75$$

The following table shows received power for the standard protected contours given above for a frequency of 100 MHz:

Contour (dBu)	Received Power (dBm)
54	-61
57	-58
60	-55

Because -55 dBm represents the protected contour of most classes of stations, this value is used as the basis for the tests. Also as discussed below, measurements were made on receivers in 1947 which led to rules that were adopted shortly thereafter. These measurements form the basis for the rules currently in force. The present interference ratios are intended to represent a desired input signal of 1 mV; the input impedance was not given in the notice.[2] Assuming this voltage was across an impedance of 300 ohms in the 1947 measurements, since 300 ohms was standard at the time, 1 mV is equivalent to a power of -55 dBm.[3]

The above field strength values are at the FCC standard antenna height of 9 meters (30 feet) that is used to determine predicted coverage. This height is generally inappropriate, and almost always incorrect for car radios. An adjustment of approximately 9 dB has been used by the Commission to adjust field strength at the standard 9 meter height to reflect low height (approximately 1.5 meters) in the mobile services.[4] This value is approximate and somewhat

[2] NPRM in Docket No. 9407 adopted and released August 4, 1949.
[3] Ibid.
[4] Roger Carey, FCC Report R-6406, "Technical Factors Affecting the Assignment of Facilities in the DPLMRS" used 9 dB.

arbitrary; the value is a function of frequency and terrain roughness, for example.[5] The difference between FM city grade (70 dBu) and 60 dBu is 10 dB. Thus, a round and convenient value of 10 dB is used here for the height adjustment to characterize desired signal level.

Testing at additional desired signal levels higher than that representing 60 dBu is desirable so that the performance of the noisier receivers will not be limited by receiver noise. As noted above, an additional 10 dB would raise the level to city grade. Thus, measurements at a desired input equivalent to city grade at 9 meters receiving antenna height (-45 dBm) are taken. This would also be approximately equivalent to a relatively strong signal case at the 80 dBu contour for a 1.5 meter receiving antenna height. In addition, measurements with a desired input level of approximately -65 dBm are desirable to represent receivers with low antenna heights at the 60 dBu contour. Thus, measurements are made with desired signal levels of -65 dBm, -55 dBm and -45 dBm to represent a variety of receiving conditions. The measured desired to undesired ratio in some cases may be a function of the level of the desired signal. Use of multiple desired signal strengths also permits the acquisition of data on such "non-linear" effects.

Signal-to-noise Ratio For The FCC Standards

The FCC's second- and third-adjacent channel interference FM protection standards were adopted 50 years ago, in 1949, and earlier in the case of the co-channel and first-adjacent

[5] NAB Engineering Handbook, 8th Edition, p 1246 recommends 7 to 9.5 dB to adjust to 3 meters from 9 meters for low VHF TV depending on terrain. Recommended values vary with frequency band. The theoretical plane earth value is 15.6 dB for 9 to 1.5 meters, independent of frequency.

channel ratios.[6] The audio S/N used in the development of these standards is not certainly known. In the Notice Of Proposed Rule Making (NPRM) in Docket 9407, the Commission specified that the ratios are based upon measurements for "... a 50 decibel rejection of the undesired signal with the desired signal modulated 30 percent and the undesired signal modulated 100 percent."[7] It is notable that the 50 dB audio suppression (a measure of signal-to-noise ratio) compares to the 50 dB audio S/N given by the ITU Standard and used in the NAB's test program. (The ITU's procedure employs a frequency weighting filter which increases the sensitivity to upper-mid range audio signals, while the FCC's original method used no special weighting filter. However, the FCC used a lineup level of 30% modulation, which is approximately 9.5 dB below the 90% modulation lineup used in the ITU's and NAB's procedures.) In the FCC's original test procedures, the metering equipment was an oscilloscope, again closely resembling the quasi-peak reading meter required by the present ITU standard. The modulating signals were probably tones, such as 1 kHz and 400 Hz. Also, at least some observations were apparently made for a number of desired signal levels and non-linear effects were observed. Thus it appears that protection measurements were based on quality standards commensurate with the high-fidelity objective of FM broadcast transmission.

The Commission's Laboratory Division conducted a series of measurements of FM receiver characteristics, including interference susceptibility in Project No. 22231 in 1947. There are

[6] The second and third adjacent channel interference ratios were adopted in FCC Docket No. 9407.

four reports in Project No. 22231 in 1947 that cover the tests. Although it is not stated in Docket No. 9407 that the results of these tests were used, there is agreement in general between the reports and the NPRM. However, there are differences. For example, the lab reports were made for mainly desired signal levels of 0.35 mV and 3.5 mV and some tests were made for lower levels, whereas the NPRM specified 1 mV. The value of 1 mV is approximately the geometric mean or the average in dB of 0.35 and 3.5. Thus, a single value of 1 mV could have been used to represent the two values used in the Lab tests. The Lab tests employed modulating percentages as described in the NPRM, 30 percent for the desired and 100 percent for the undesired. Four hundred Hz tones were used for both desired and undesired signals. Measurements were made for desired to undesired interference ratios of 20, 30 and 50 dB. The test procedure is shown in Appendix A. Although the 1940s techniques differ from contemporary, and presumably improved, techniques, the 1947 procedure is similar to present standards. A standard ratio was assumed and essentially peak reading devices are used in both cases; an oscilloscope was used in the 1947 tests. The greatest difference is in modulating signals. In 1947 tones were used, whereas presently shaped noise is used which more closely represents contemporary station practice. However, it is clear that the nominal standard was 50 dB and that the Commission intended to protect relatively high quality service.

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[7] NPRM in Docket No. 9407 which was adopted and released August 4, 1949. FM Rules were adopted as proposed on October 24, 1949.

An estimate of the S/N appropriate for the FCC interference standards can be made from the cochannel interference ratio of 20 dB. Cochannel interference is similar to noise in the channel. For white noise interference, a 20 dB carrier to noise ratio (C/N) is well above threshold and should produce a greater S/N, approximately 50 dB for monophonic reception.[8] When the FCC interference standards were developed by the Commission, the ratio was not for stereo because stereo did not exist at the time. Thus, the Commission apparently intended to define FM service equivalent to a S/N of approximately 50 dB.

Support for the ITU 50 dB S/N is also contained in a study conducted by the Technical Subgroup of the Advisory Committee on Radio Broadcasting.[9] The subgroup conducted listening tests relating signal-to-noise ratio to qualitative perceived impairment. Observations were made using the CCIR five point scale:

1. Very Annoying
2. Annoying
3. Slightly Annoying
4. Perceptible but not Annoying
5. Imperceptible

For the median observer a S/N of 59 dB was required for a Grade 5 (Imperceptible) signal. The values for Grades 3 and 4 are 49 dB and 54 dB, respectively. Thus, a 50 dB ratio

[8] Mischa Schwartz, Information Transmission, Modulation and Noise , 4th ed., pp 515-518.
[9] L.C. Middlecamp, Subjective Evaluation of Audio Degraded by Noise and Undesired FM Signals, November 17, 1982.

represents degradation to nearly Grade 3, Slightly Annoying, a relatively high but not an extremely high grade of service such as "imperceptible."

In the present NAB tests, signal-to-noise ratios are to be measured for the 28 tested receivers in the absence of interference for the three desired signal levels (-65 dBm, -55 dBm and -45 dBm) as described above. Although, the primary standard is a signal to noise ratio of 50 dB, there are receivers that cannot achieve such a S/N in the absence of interference. This is particularly true for the lower values of received power. For such combinations of receivers and desired power it is necessary to define a standard of degradation from the receiver's S/N in the absence of interference. Figure 1 of the technical subgroup report on the subjective tests shows that the average difference between CCIR grades is 5.0 dB for the median listener. Therefore, a degradation of 5 dB is used because it represents a change of one CCIR grade, from "slightly annoying" to "annoying," for example. The value of 5 dB represents a change readily perceptible to listeners and may be characterized in terms of the standard grades.

A 50 dB audio S/N standard or the 5 dB degradation criterion is appropriate considering that, if third adjacent, and perhaps, second adjacent channel separations are eliminated, LPFM stations may be located well within a station's protected contour where receivers are capable of their best performance. In these areas, audio quality would generally not be limited by field strength. This raises the issue of strong signal performance of receivers. If non-linear interference mechanisms, such as cross modulation, contribute to S/N degradation, measured D/U will decrease with increasing desired signal level. The use of multiple desired signal levels covering a range of -65 dBm to -45 dBm permits the indication of non-linear effects over a range of 20 dB for the desired signal.

Summary and Conclusions

To conduct tests on the interference susceptibility of contemporary FM broadcast receivers, an audio standard of service, that is an audio signal-to-noise ratio (S/N) must be defined. In addition the level of the desired signal must be specified. In summary, a S/N of 50 dB is used as the basic standard. This is considered to be the ratio used by the Commission in the development of the FM standards and is specified by the ITU for FM interference testing. For receivers incapable of producing a S/N greater than 50 dB, a degradation in dB is applied to the measured signal-to-noise. In these cases, the measured D/U is determined for a decrease in audio S/N of 5 dB. The value of 5 dB represents a change of one CCIR grade. The degradation factor is applied when S/N without interference is less than 55 dB so that in any case degradation is at least 5 dB. Measurements are made for three desired signal levels on all receivers (-65 dBm, -55 dBm and -45 dBm) to represent a variety of receiving conditions. The value of -55 dBm represents reception at a station's 60 dBu (1 mV/m) contour with an antenna at the FCC standard 9 meters (30 feet) above ground. Non-linear effects where D/U depends on the strength of the desired signal may be observed in those receivers exhibiting such characteristics because multiple desired signal strengths are used in the tests.

AFFIDAVIT

COUNTY OF ARLINGTON)
) SS:
COMMONWEALTH OF VIRGINIA)

JOSEPH W. STIELPER, being duly sworn upon oath deposes and says:

That he is employed as a Senior Engineer by the firm of JMS Worldwide, Inc. d/b/a MLJ consulting telecommunications engineers;

That this firm has been retained by the National Association of Broadcasters to prepare this engineering statement;

That he has either prepared or directly supervised the preparation of all technical information contained in this engineering statement; and that the facts stated in this engineering statement are true of his knowledge, except as to such statements as are herein stated to be on information and belief, and as to such statements he believes them to be true.

Joseph W. Stielper

Joseph W. Stielper

Subscribed and sworn to before me this 21st day of July, 1999

Jacqueline Marie Richardson

Jacqueline Marie Richardson, Notary Public

My commission expires October 31, 2001.

AFFIDAVIT

COUNTY OF ARLINGTON)
) SS:
COMMONWEALTH OF VIRGINIA)

JOHN C. KEAN, being duly sworn upon oath deposes and says:

That he is employed as a Director of Engineering by the firm of JMS Worldwide, Inc. d/b/a MLJ consulting telecommunications engineers;

That this firm has been retained by the National Association of Broadcasters to prepare this engineering statement;

That he has either prepared or directly supervised the preparation of all technical information contained in this engineering statement; and that the facts stated in this engineering statement are true of his knowledge, except as to such statements as are herein stated to be on information and belief, and as to such statements he believes them to be true.

John C. Kean

John C. Kean

Subscribed and sworn to before me this 21st day of July, 1999

Jacqueline Marie Richardson

Jacqueline Marie Richardson, Notary Public

My commission expires October 31, 2001.

National Association of Broadcasters
Washington, DC

Appendix A
Project No 22231 Test Procedure

PROCEDURE

A. INTERFERENCE REJECTION RATIOS (SELECTANCE)

DEFINITIONS.

R.F. Carrier Ratio. Two signal generators were employed to simulate a "desired" signal and an "undesired" signal, hereinafter designated as “D" and “U”, respectively. These symbols also conveniently represent the magnitude of their R.F. voltages as impressed on a dipole antenna having a 300-ohm transmission line connected to an assumed 300-ohm input impedance. “U/D" is therefore the numerical ratio of the carrier voltages, and is known as the R.F. Carrier Ratio. “D” was modulated 30 percent at 400 cycles sec., i.e., the deviation was plus and minus. 22.5 kc. “U” was modulated 100 percent at 400 cycles/sec., i.e., 75 kc. deviation.

Rejection Ratio. With “D" at a suitable level, its modulation was applied, and the receiver under test tuned (after adequate warmup period) for maximum audio signal at the center response of the usual three responses shown by the discriminator[1] . The audio volume control was set to produce 0.5 watt in a dummy load. An oscilloscope

[1]Standard discriminators and ratio detectors show these triple responses.
The "locked oscillator" set used has more complex responses.

(connected for convenience between control grid of one of the audio output tubes and ground) displayed a peak-to-peak representation of the voltage existing at that point. This voltage is known as E_G and is measured by comparison with the internal 60-cycle calibrating voltage of the 715-B oscilloscope. Output voltages 20, 30 and 50 db below E_G were calculated and are known as E_{20}, E_{30} and E_{50}, respectively. E_G was then eliminated, by removing the modulation of "D". The only remaining voltage shown by the oscilloscope then was hum and/or shot noise. The ratio between E_G and E_{20}, E_{30} or E_{50}, is the Rejection ratio in db.

"U" was next set to the desired interference frequency, either co-channel or some frequency removed by a multiple of 200 kc. (one channel width) from the frequency of "D". With modulation applied to its carrier, "U" was increased so as to produce E_{20}, E_{30} or E_{50}, as observed on the oscilloscope. It should be noted here that these voltages are each composed of true interference plus any shot noise existing. They appear superimposed on the residual hum of the set, which is subtracted out. For the various interference levels, E_{20}, E_{30} and E_{50}, the value of "U" was noted.

Tests of this character were conducted at levels of 3500 and 350 microvolts for "D". Tests were also made at a level between 35 and 70 microvolts depending upon the sensitivity of the receiver under consideration. The signal generators were so connected that the impedance presented to the receiver terminals was 300 ohms at all times, by the use of suitable series resistors. A numerical ratio of 10:7 existed between the signal generator attenuator settings and the actual voltage at the set terminals. In this way 5,000 microvolts indicated on the attenuator was equal to 3500 microvolts applied to the receiver through a 300-ohm dummy antenna.

EXHIBIT B:

FM Receiver Interference Test Results Report